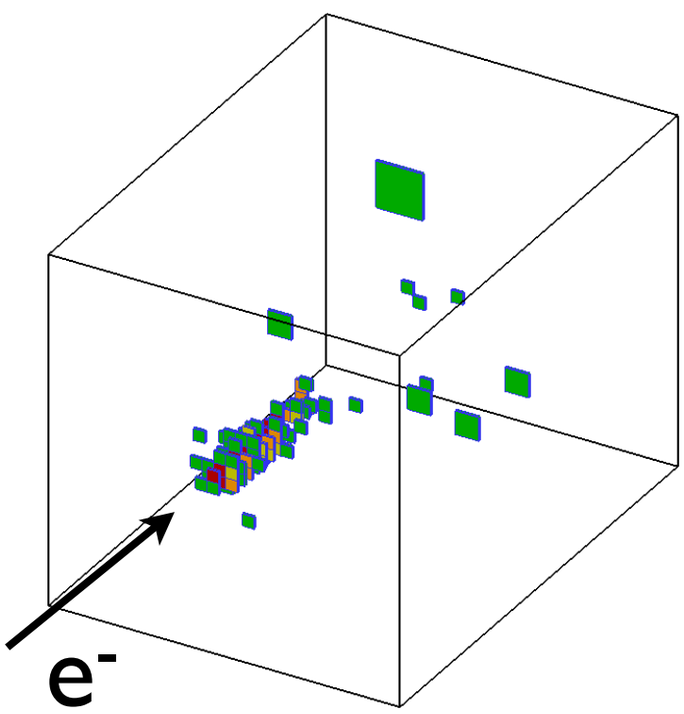
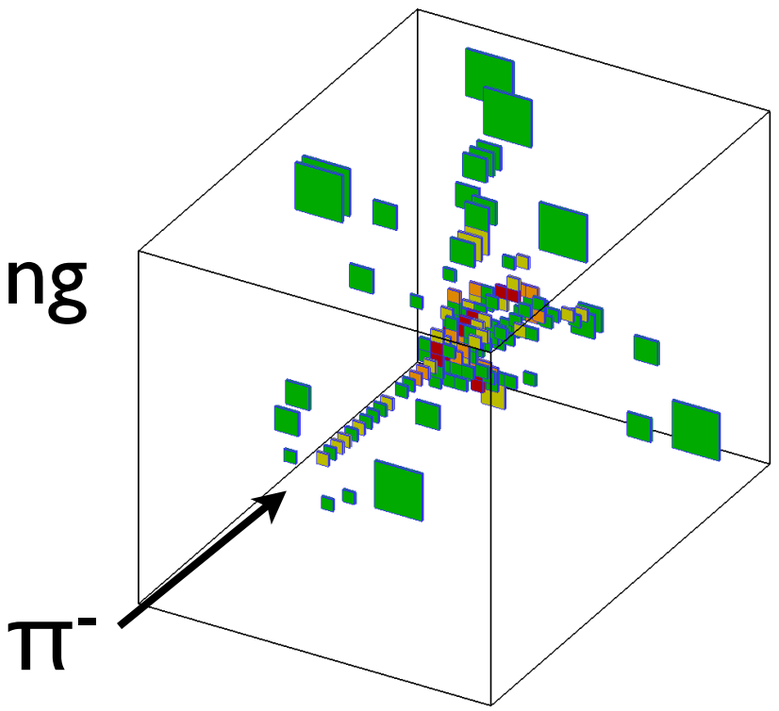
Stony Brook University

A Brief Introduction To Calorimetry

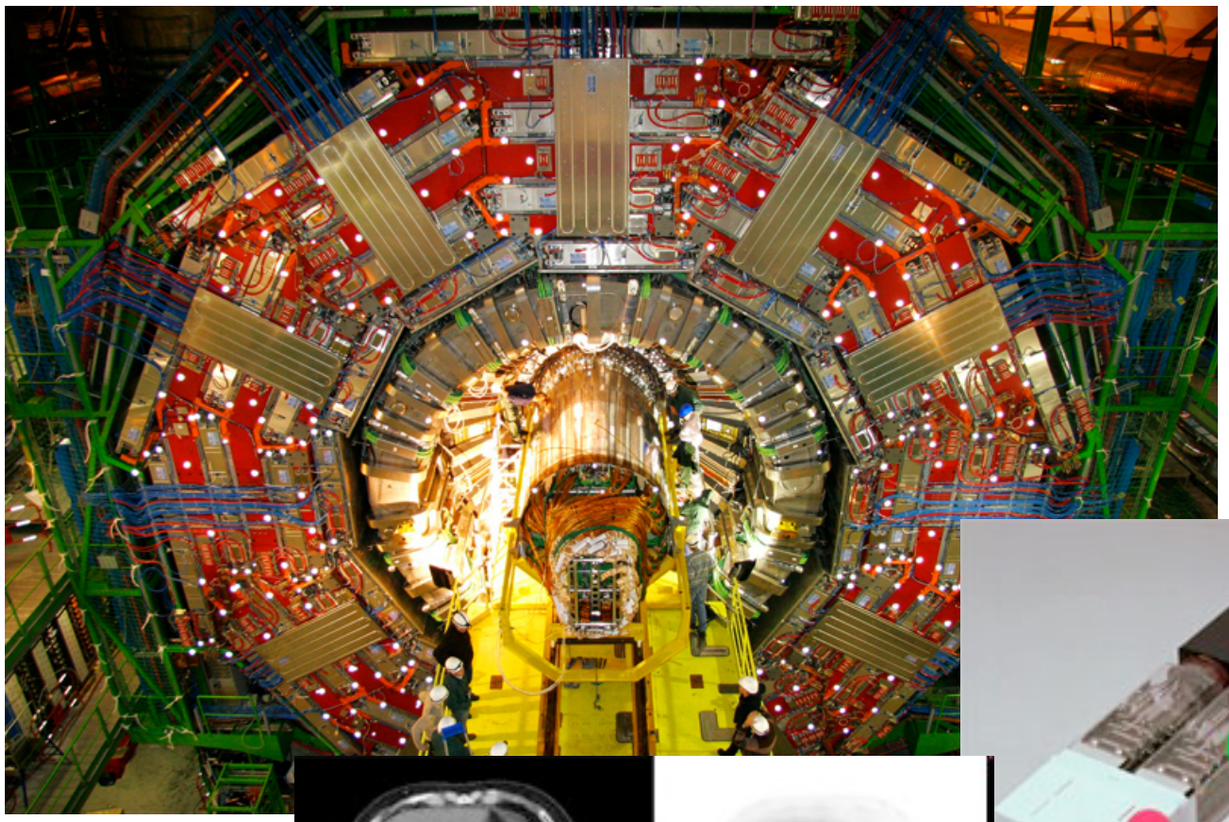


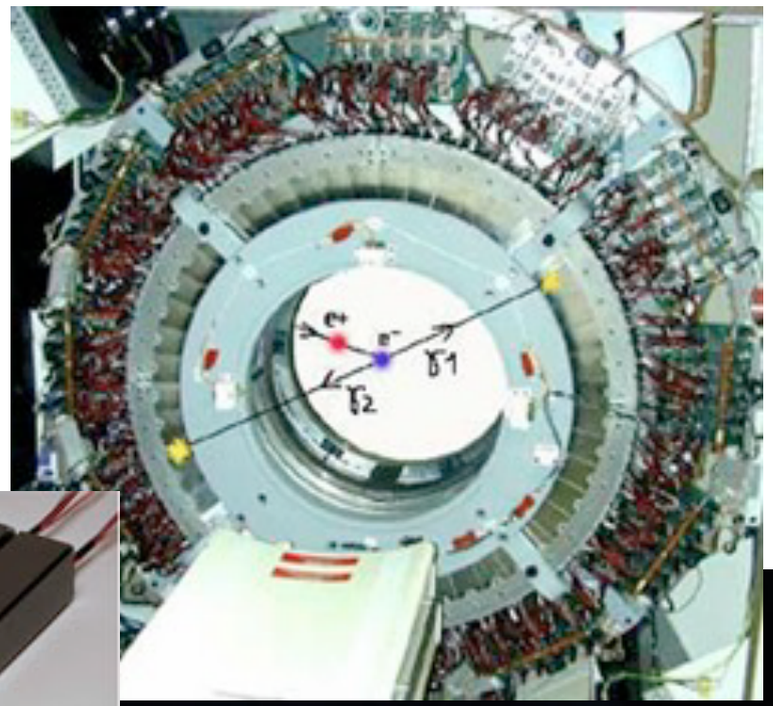
Nils Feege

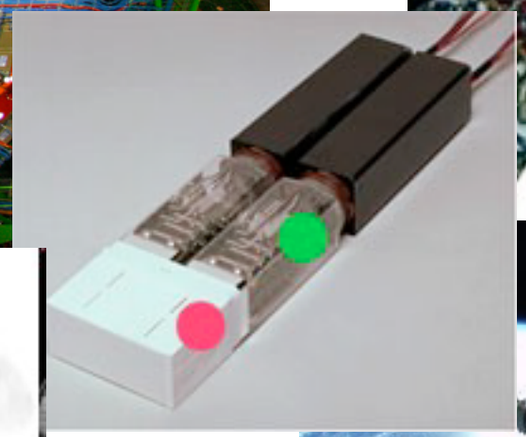
Stony Brook Local Meeting
February 21, 2014

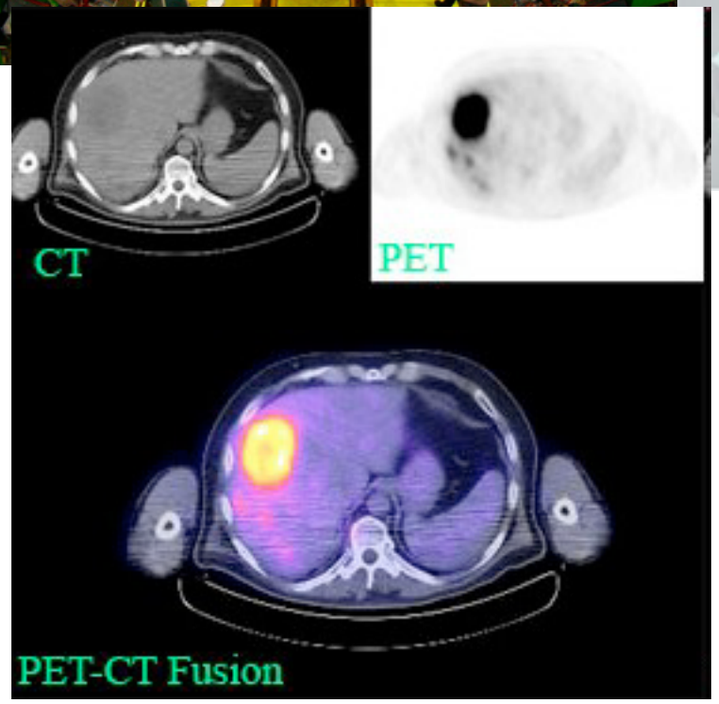


Calorimeters are used everywhere

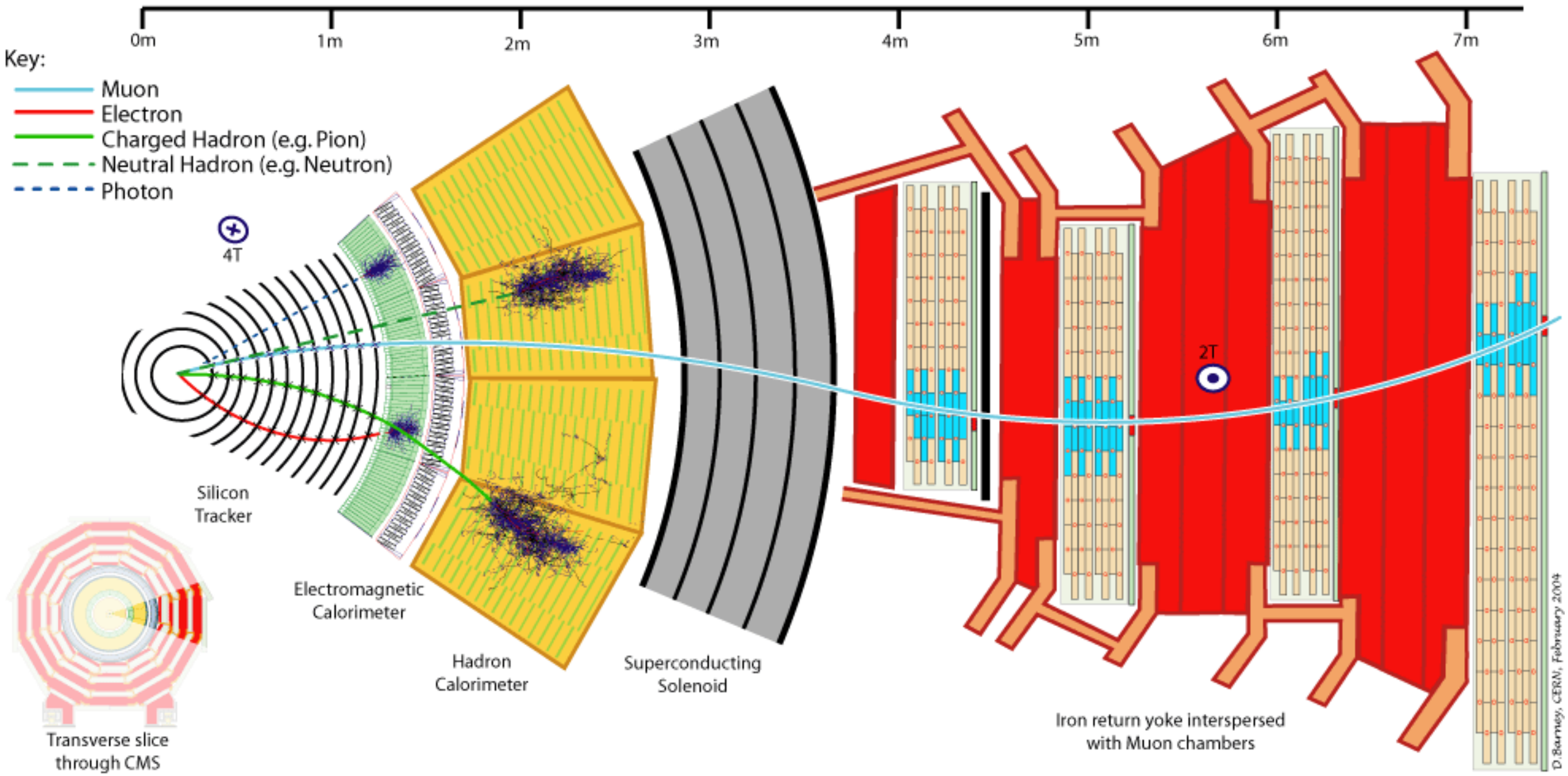








Calorimeters measure particle energies by total absorption



Why Calorimeters?

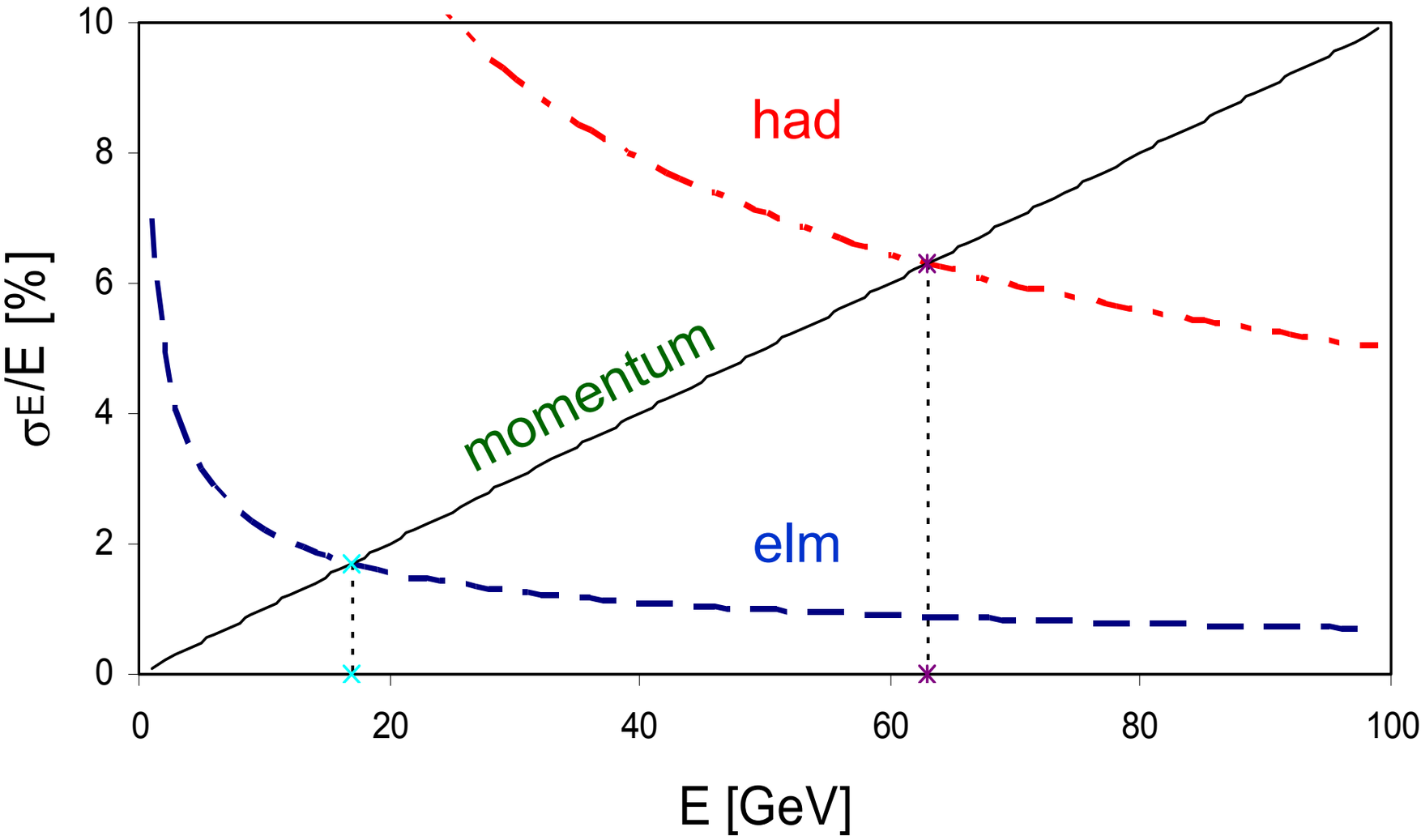
- Momentum (tracker) and energy (calorimeter) resolutions:

Tracker (momentum)

$$\frac{\sigma_p}{p} \approx 0.1 \ldots 1\,\% \cdot p/\mathrm{GeV}$$

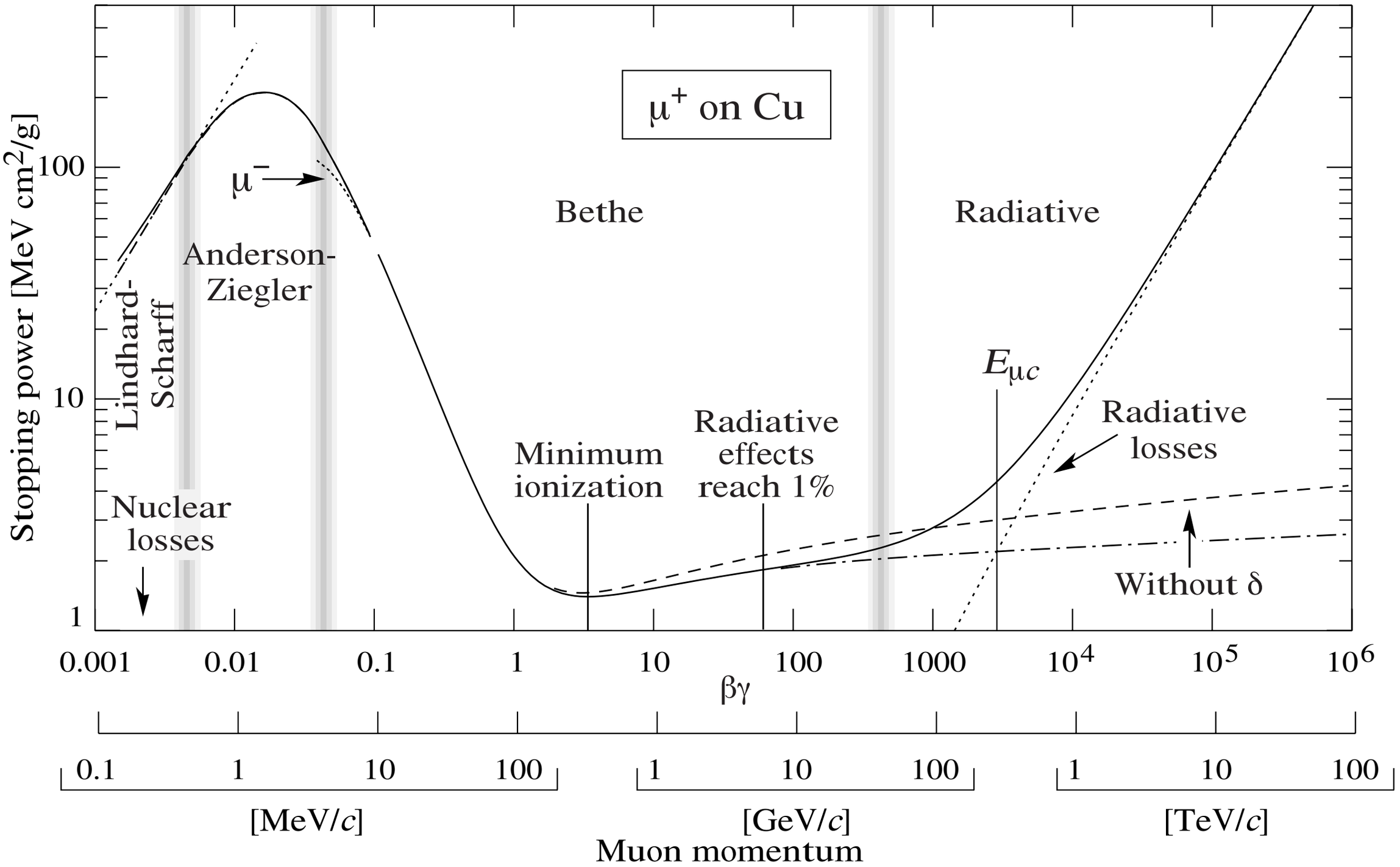
Calorimeter (energy)

$$\frac{\sigma_E}{E} \approx \begin{cases} \dfrac{2-15\,\%}{\sqrt{E/\mathrm{GeV}}} & \text{elm.} \\ \dfrac{35-120\,\%}{\sqrt{E/\mathrm{GeV}}} & \text{had.} \end{cases}$$

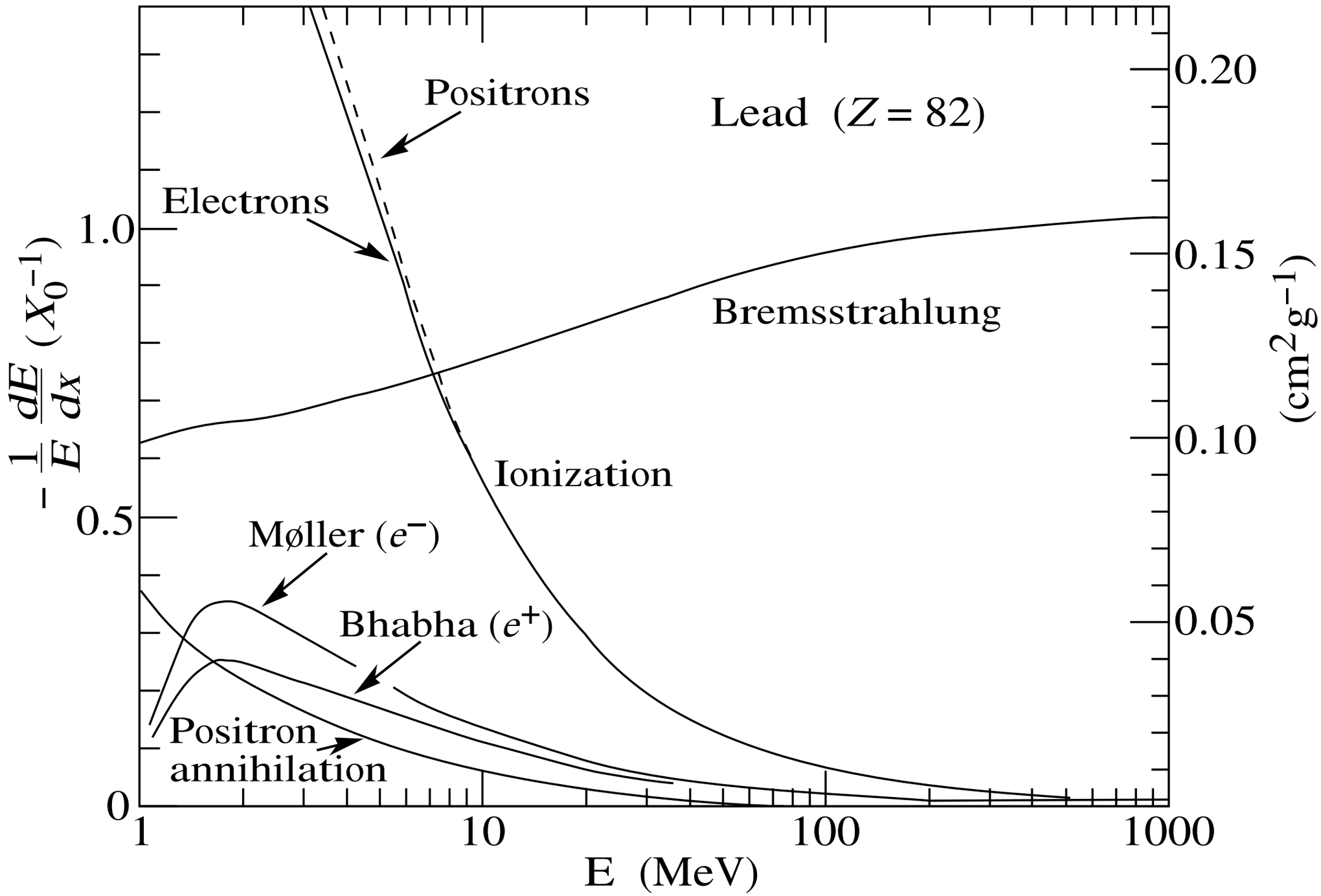


- Measure charged and neutral particle (and 'missing') energy.
- Fast signal generation.

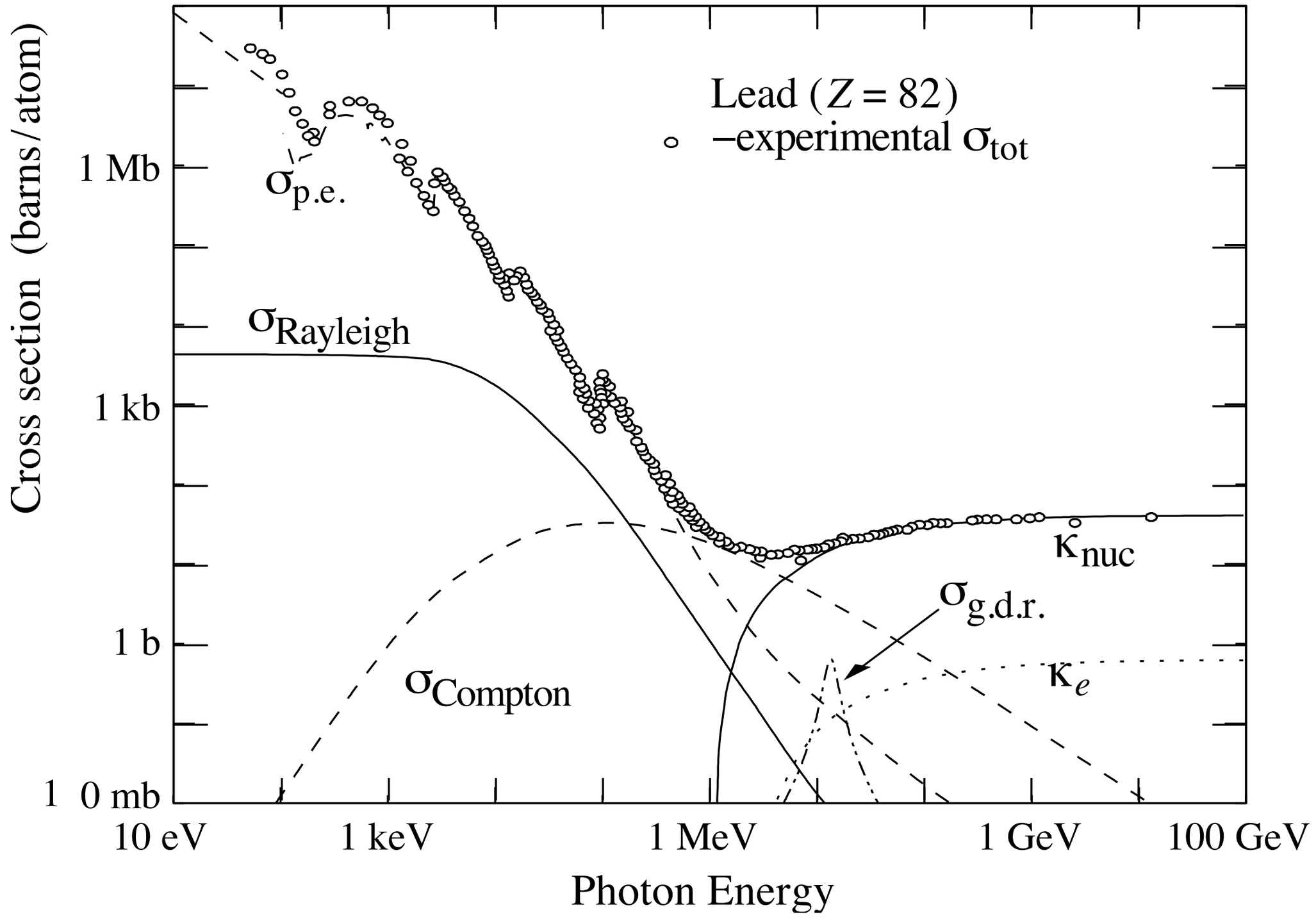
Muon Energy Loss



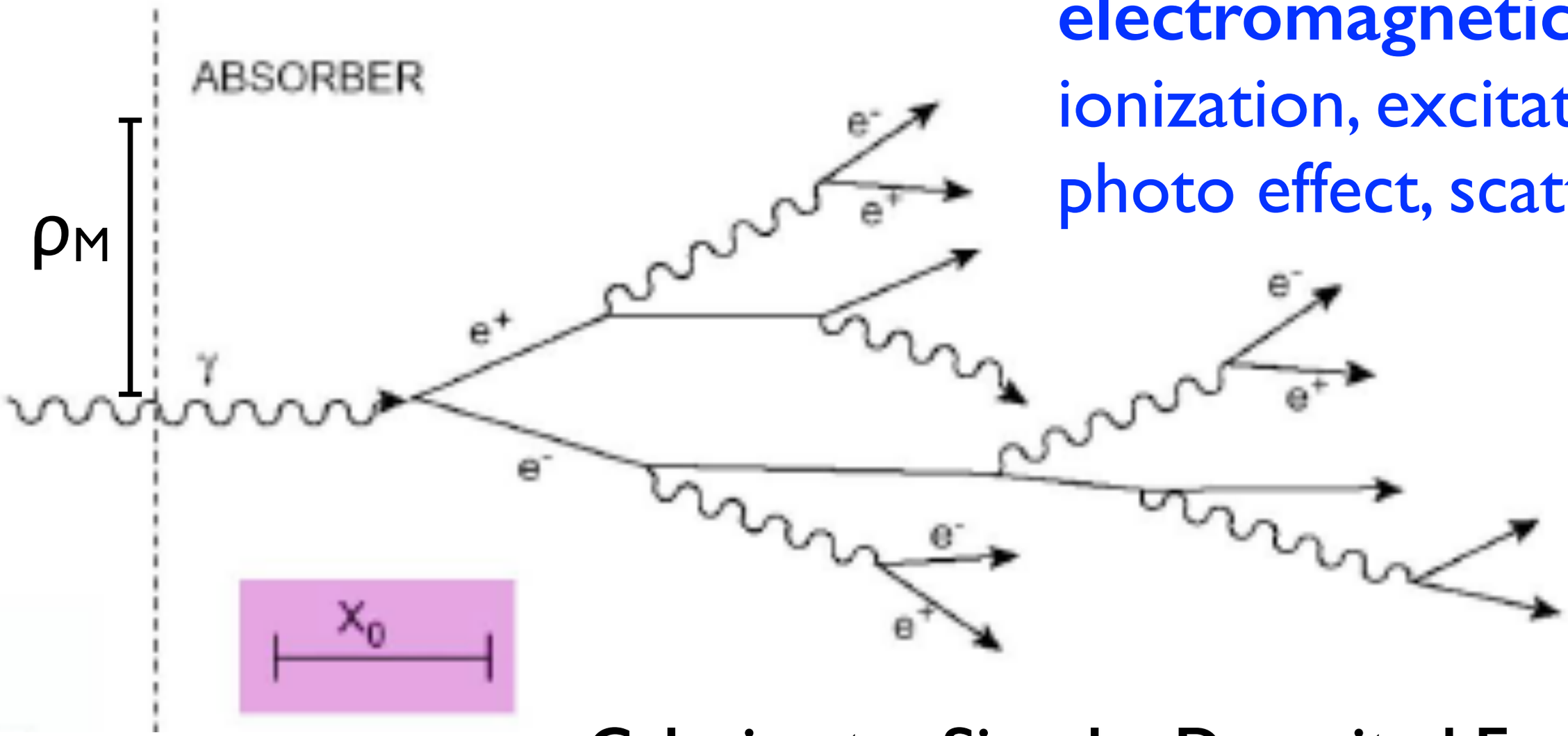
Electron / Positron Energy Loss



Photon Energy Loss



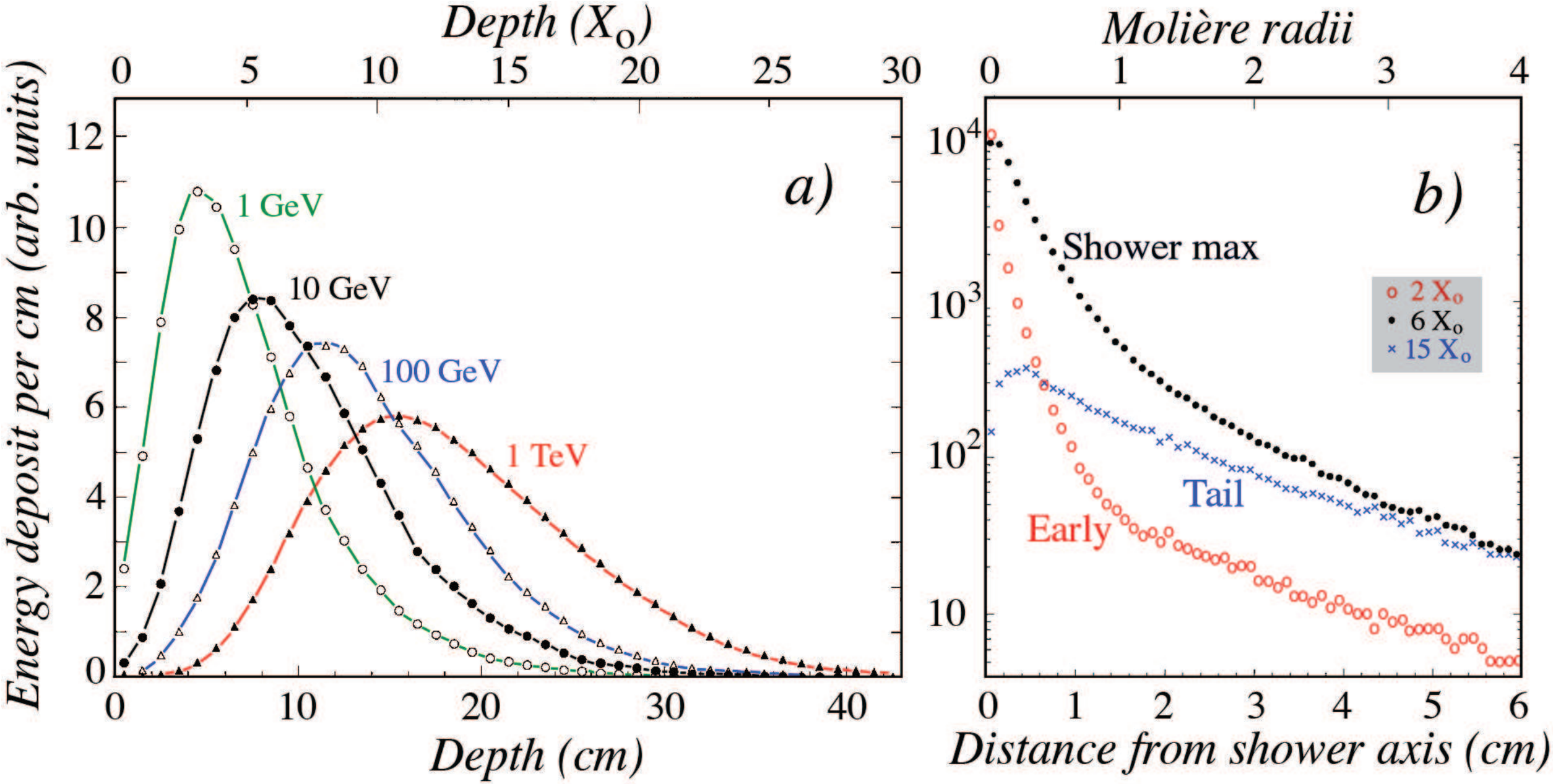
Anatomy of an electron / photon cascade



electromagnetic:
ionization, excitation,
photo effect, scattering

Calorimeter Signal ~ Deposited Energy

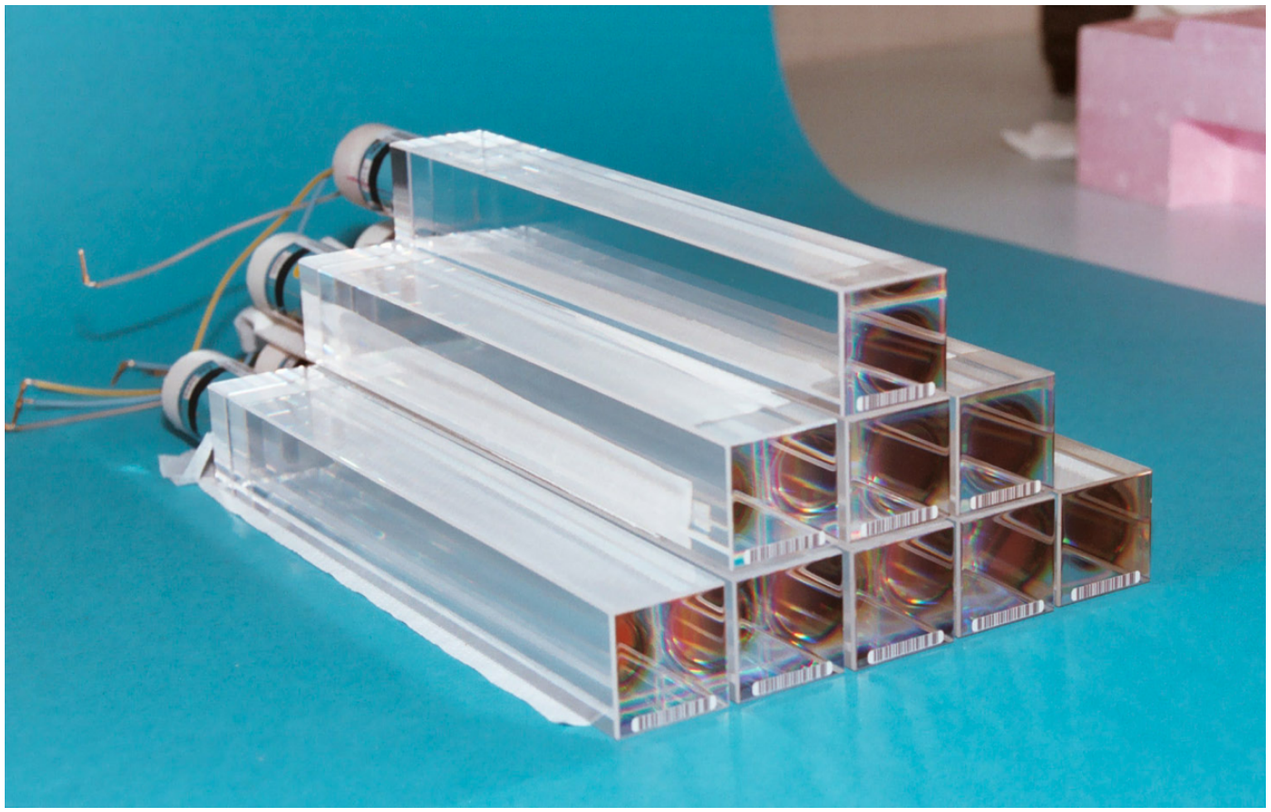
Longitudinal Cascade Development

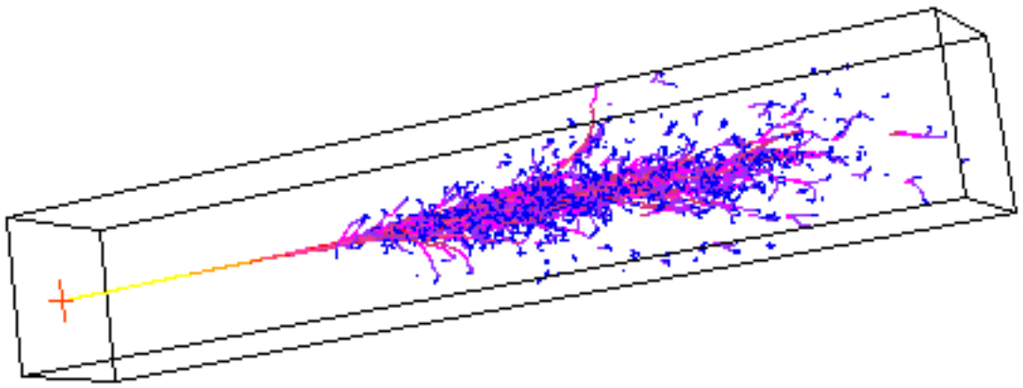


Cascade depth ~ln(E) makes calorimetry feasible!

Basic Calorimeter Types

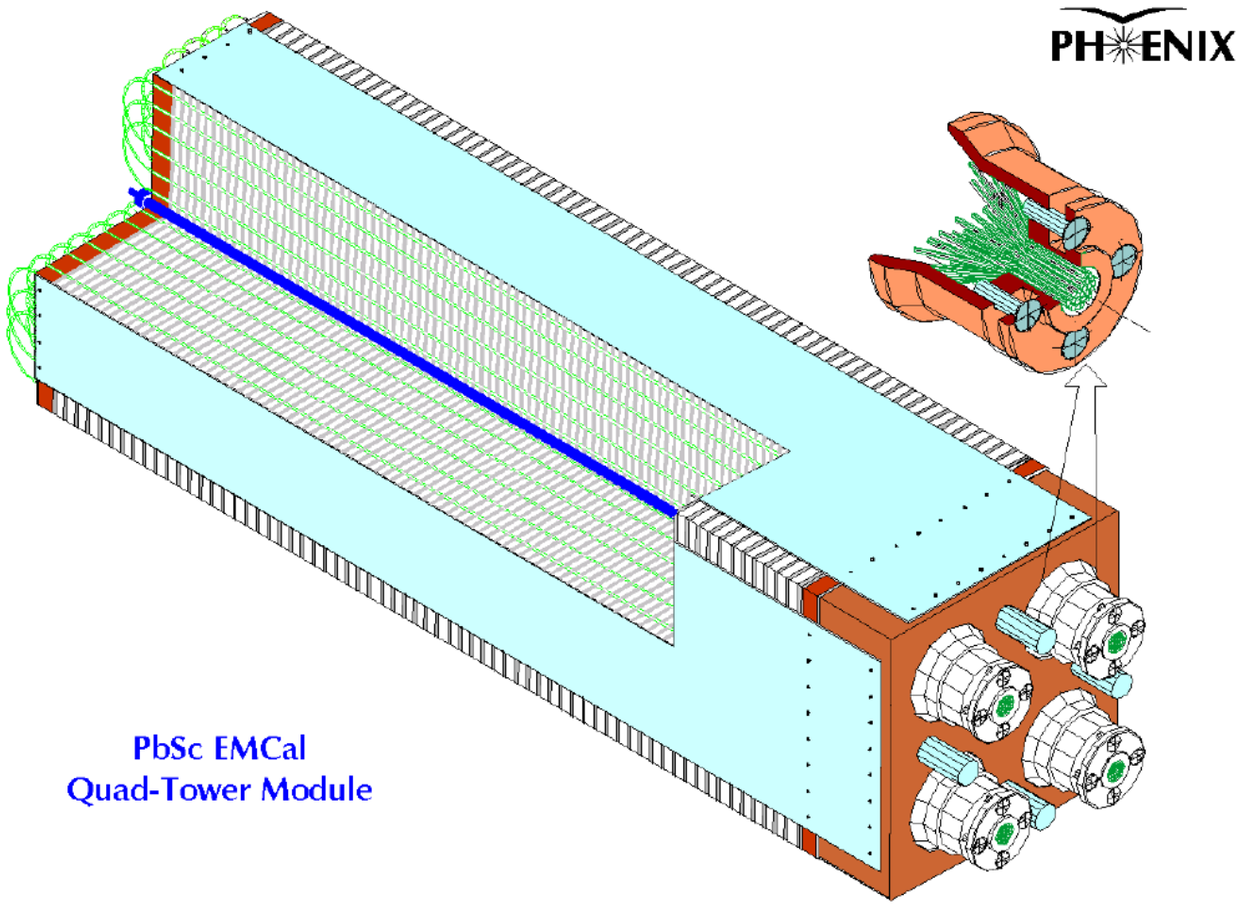
Homogeneous

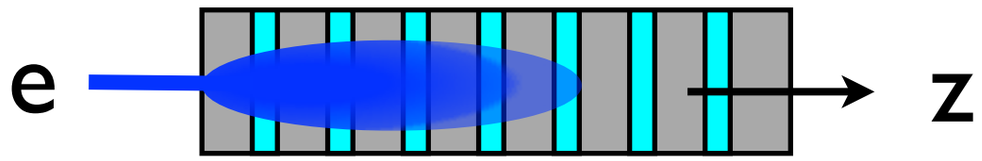




CMS ECAL: $PbWO_4$

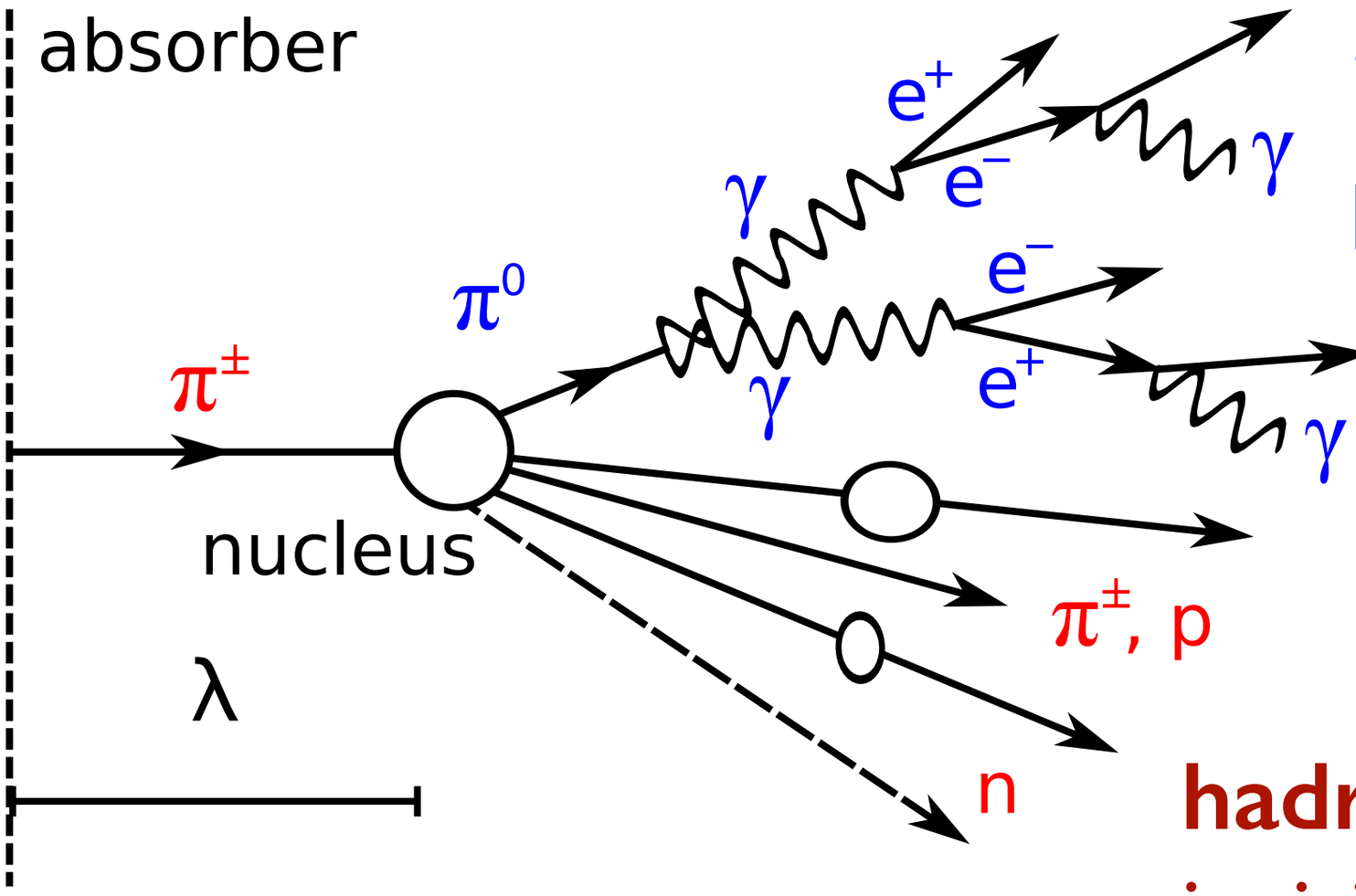
Sampling





PHENIX ECAL: Pb / Scintillator

Anatomy of a hadronic cascade

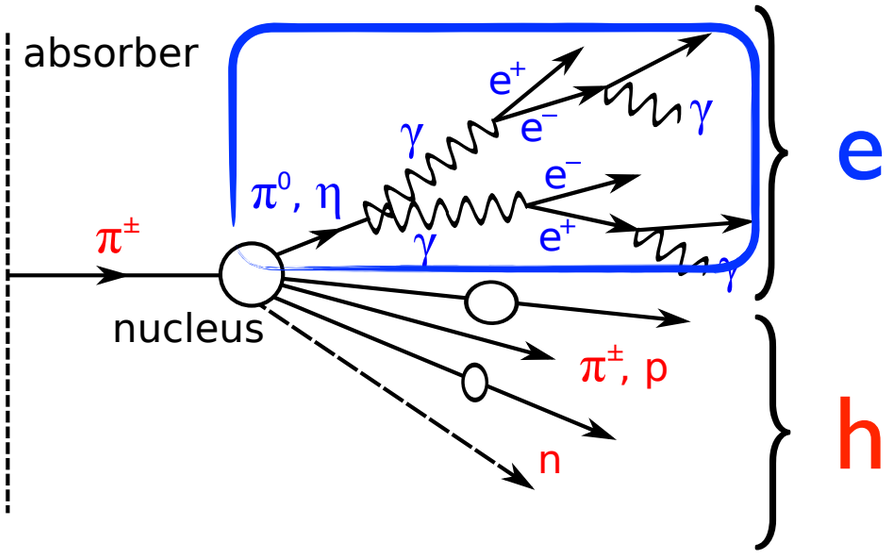


electromagnetic:
ionization, excitation,
photo effect, scattering

hadronic: ionization,
invisible (binding, recoil)

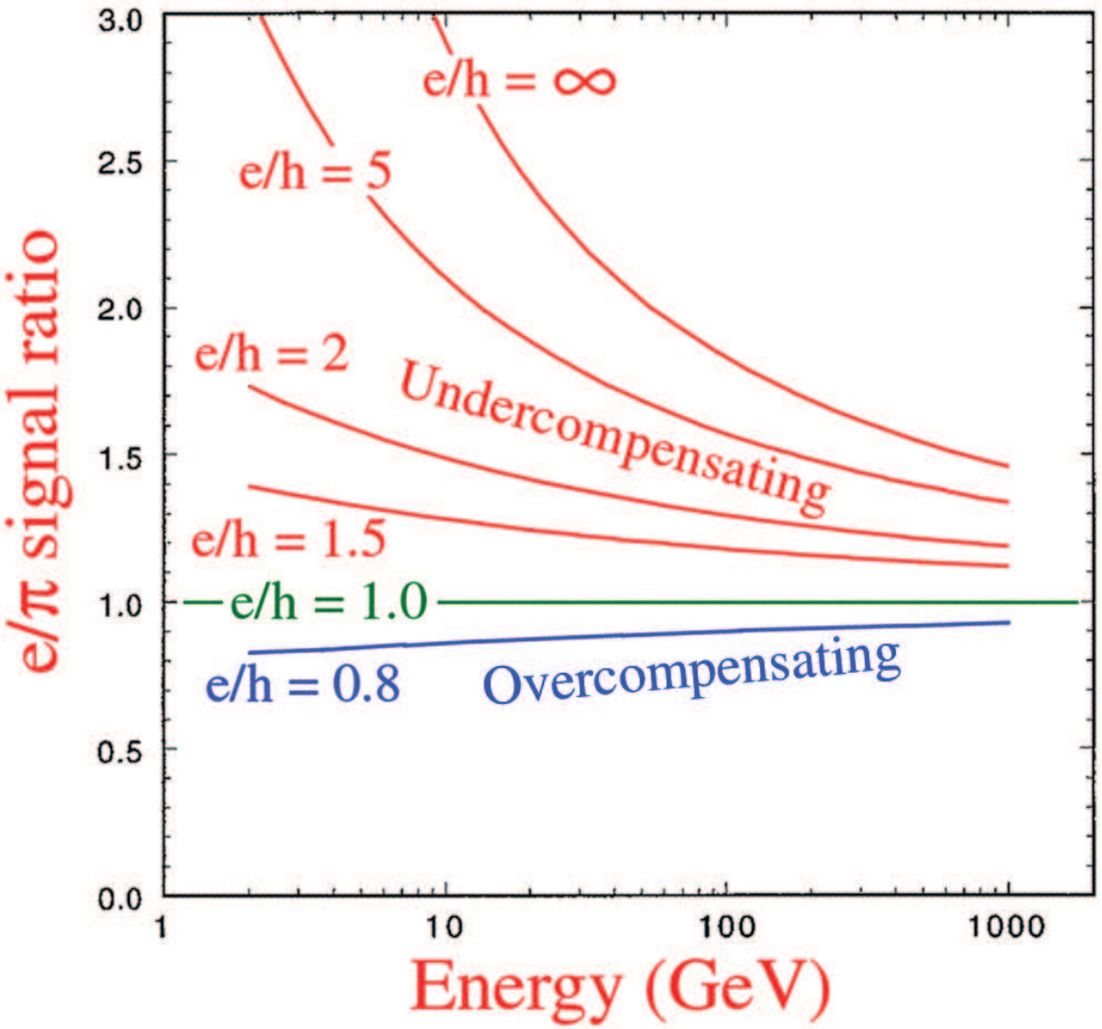
→ Very large fluctuations from one cascade to another.

Calorimeter response to pions



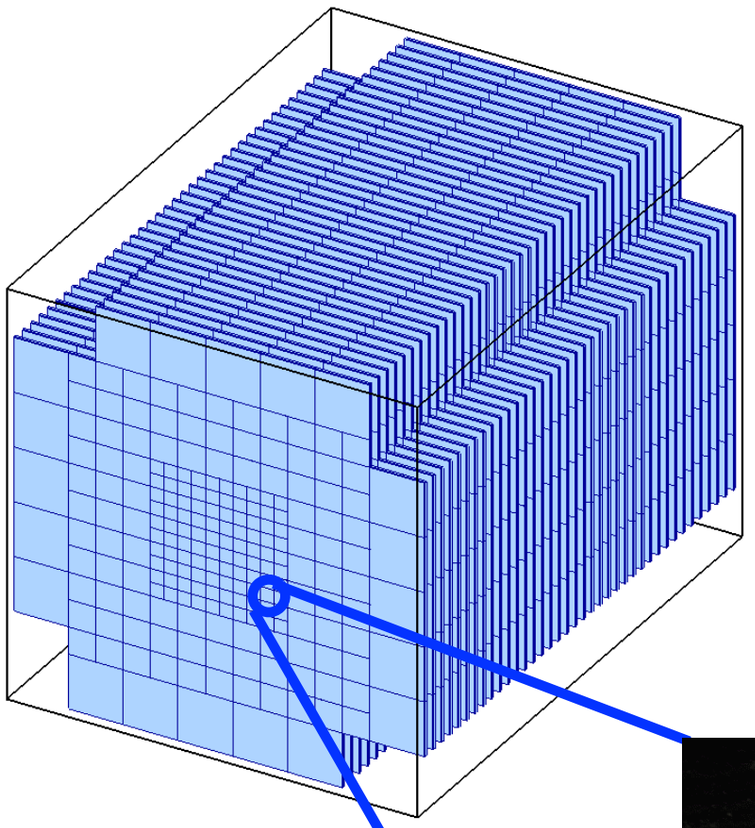
usually e ≠ h

$$f_{em} = 1 - \left(\frac{E}{1\,GeV}\right)^{-k}$$



$$\frac{E^{\pi}_{rec}}{E_{beam}} = e \cdot f_{em} + h \cdot (1 - f_{em})$$

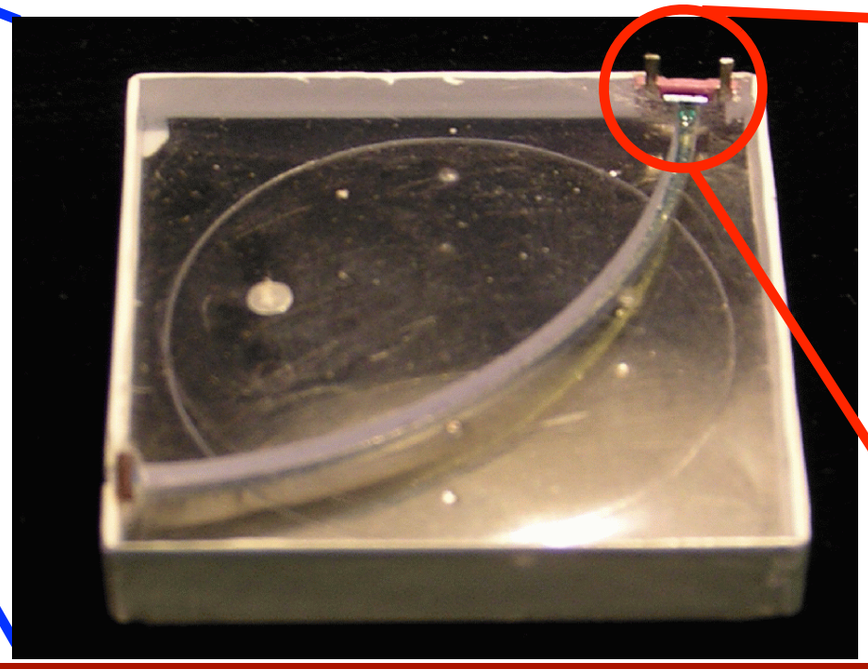
CALICE Analog Hadron Calorimeter

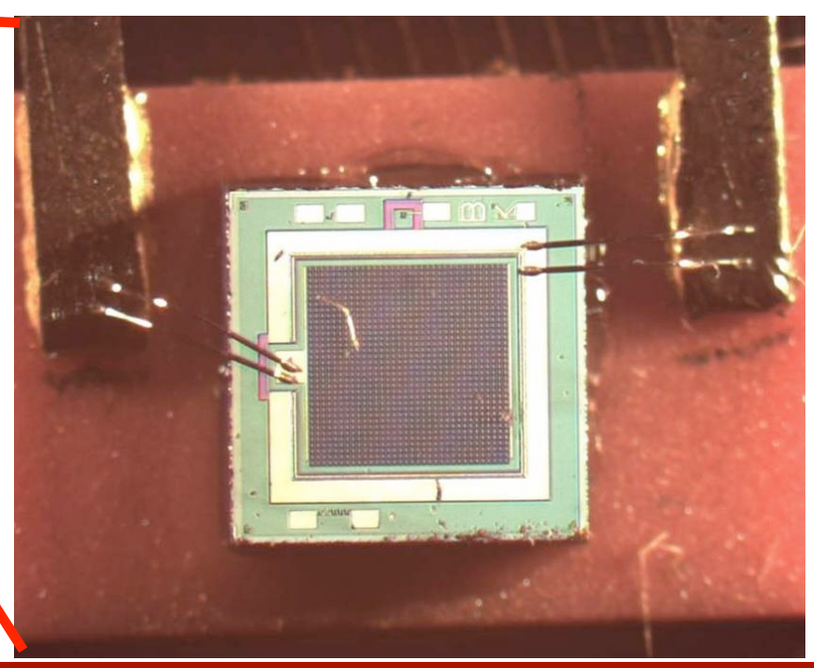


1 prototype (1 m^3)

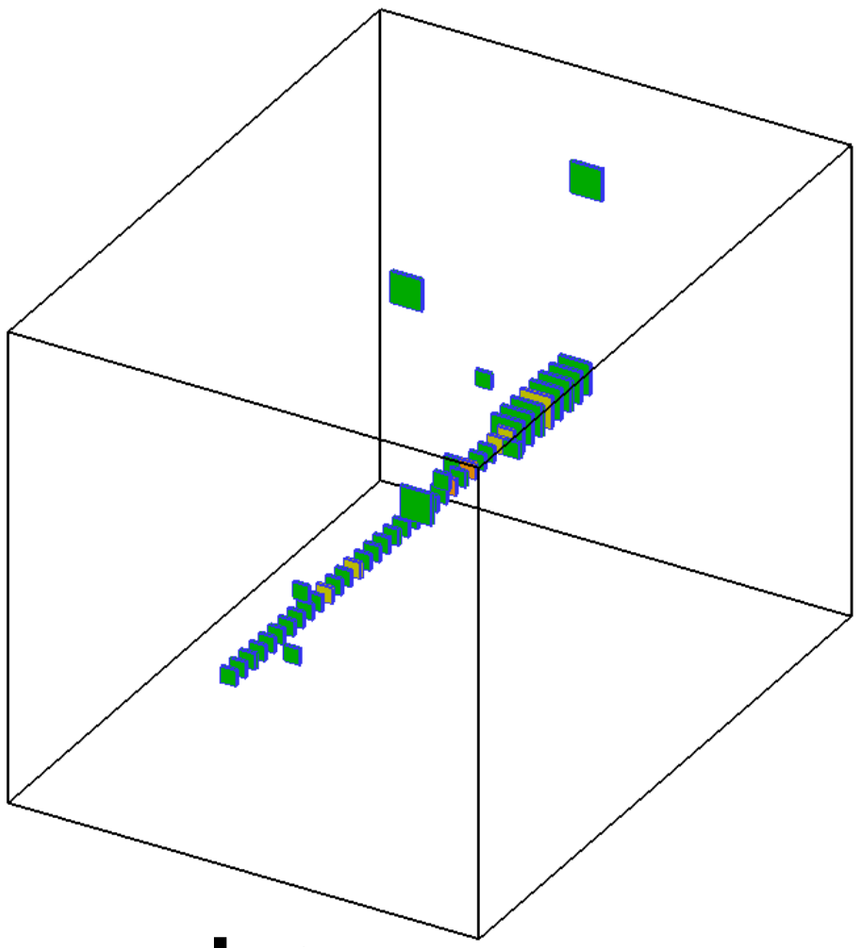
- 38 sensitive layers (scintillator, 5 mm)
  + absorber (steel, 2 cm)
- 216 scintillator tiles (3x3 ... 12x12 cm^2)
- 1 photodetector (SiPM, 1x1 mm^2)

~ 8 000 read-out channels

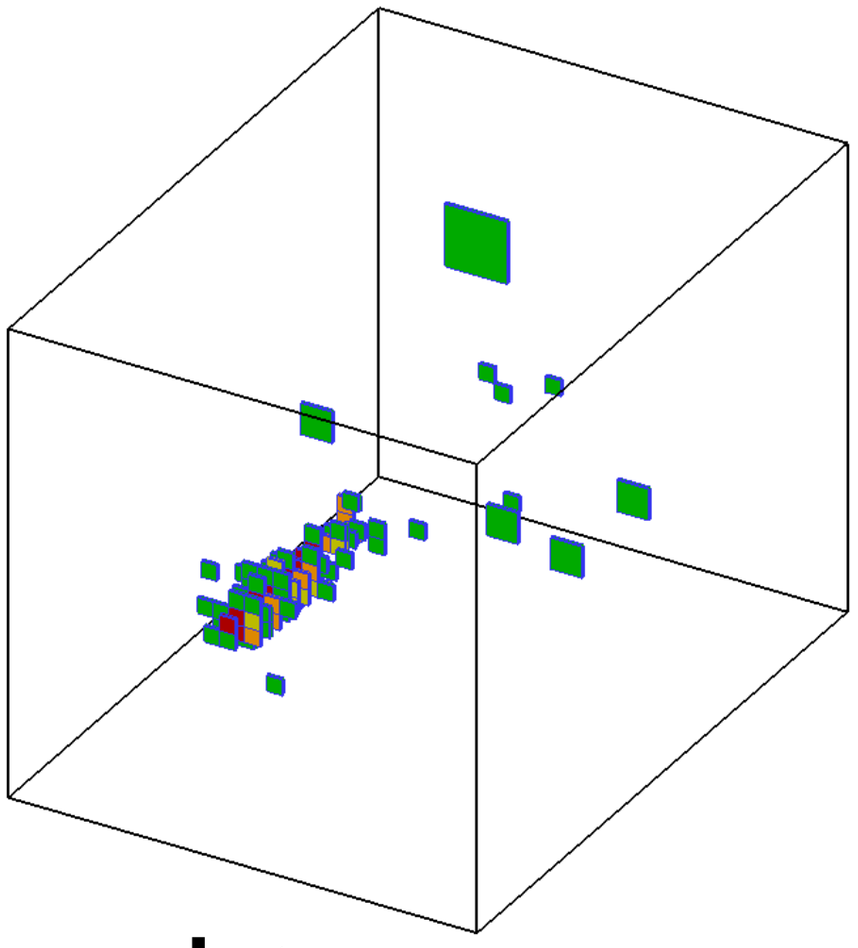




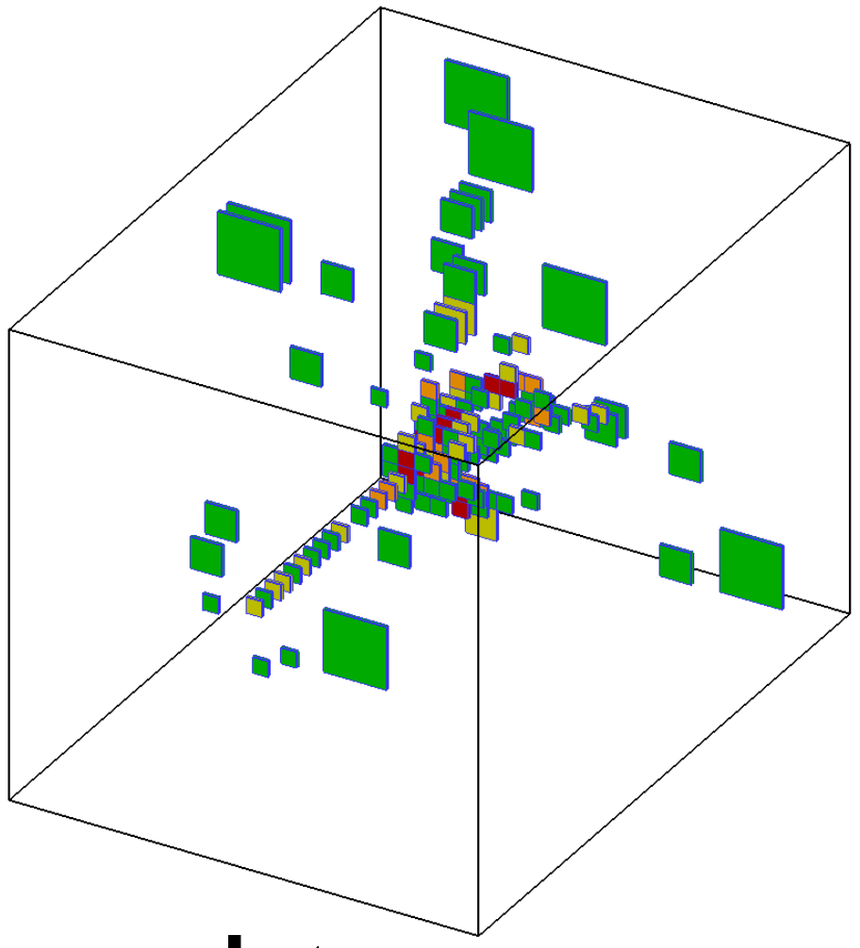
The Dawn of 3D Imaging Calorimetry



μ^- data

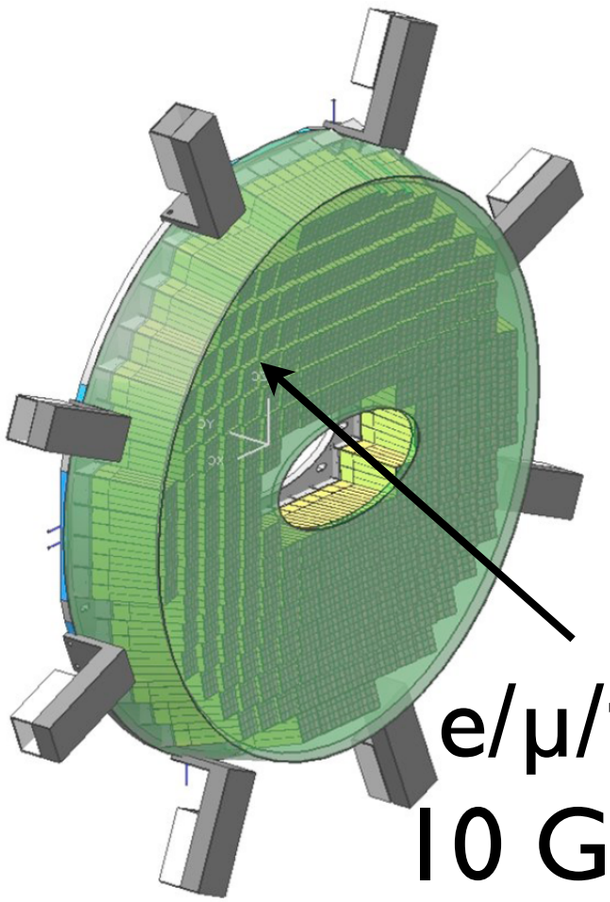


e^- data

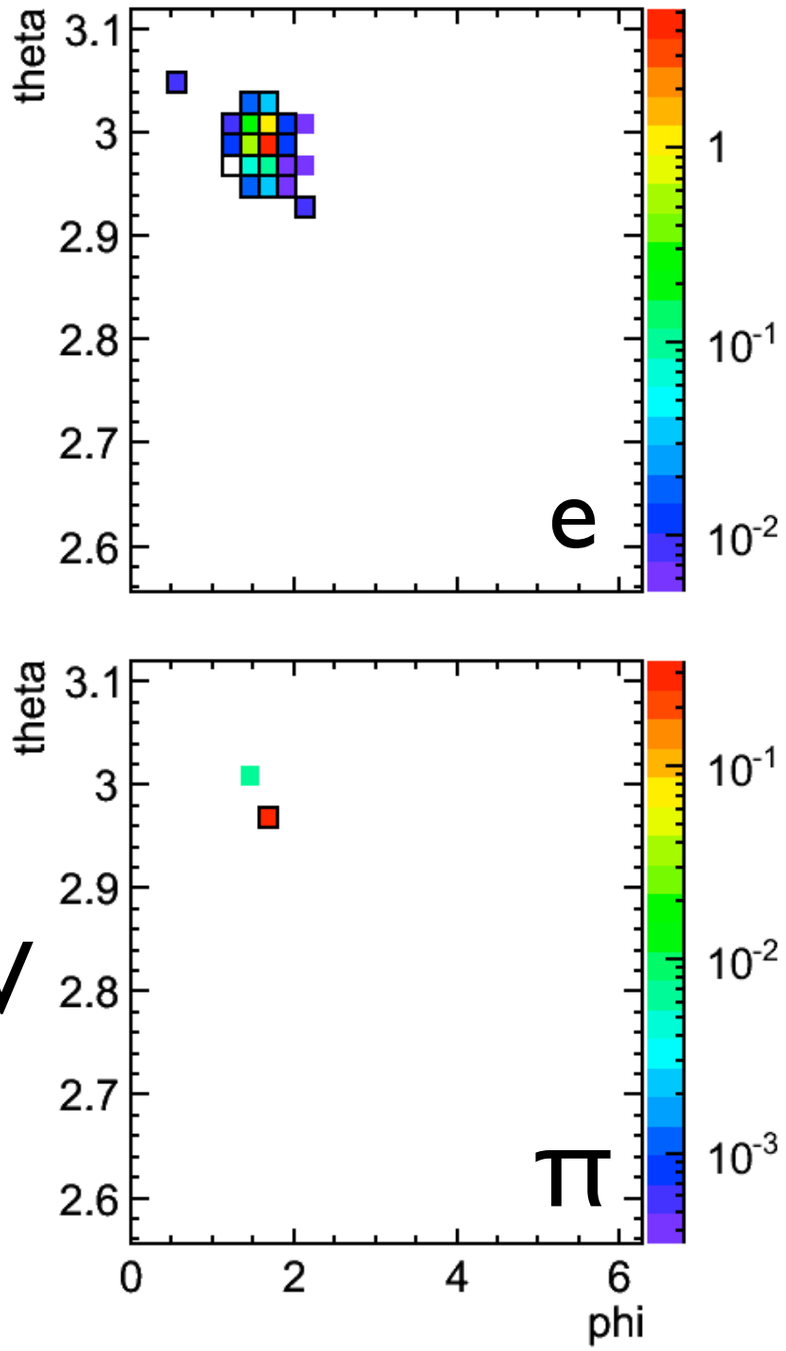


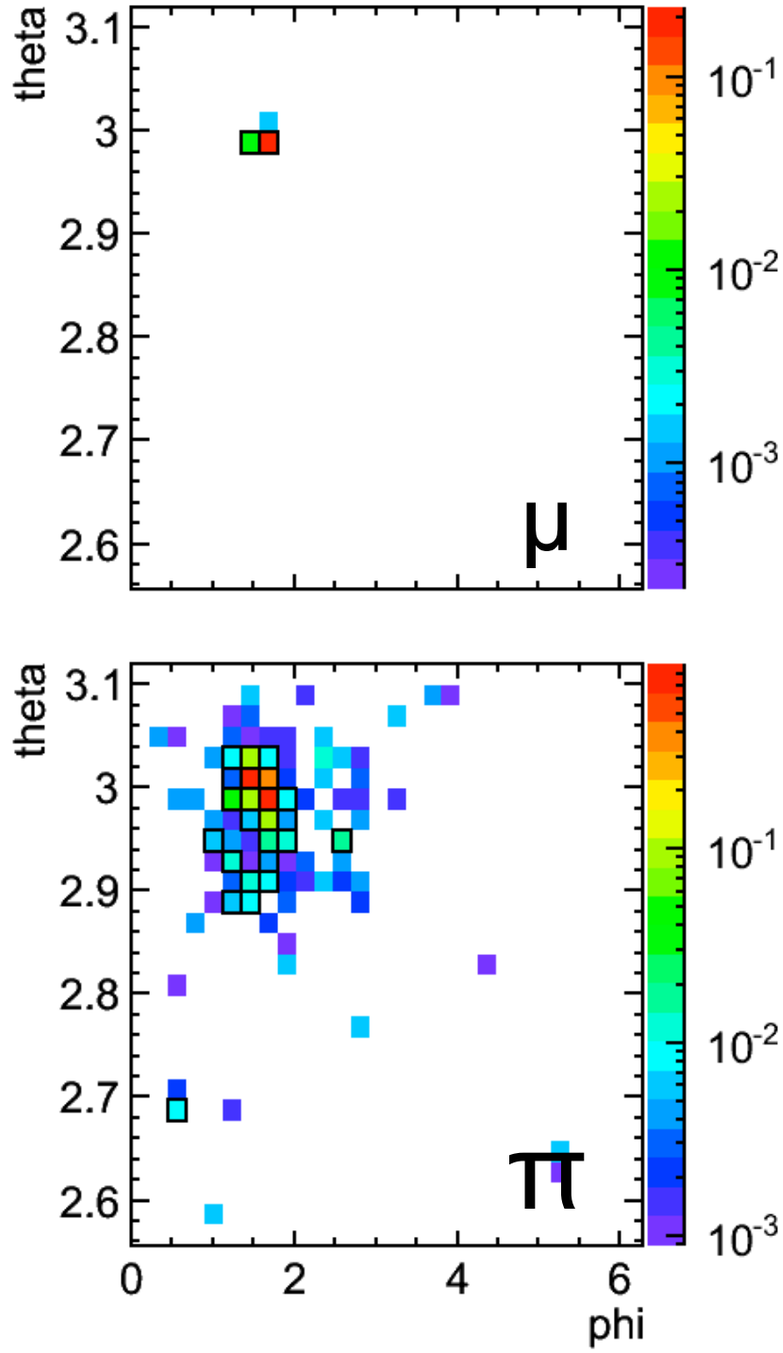
π^- data

EIC PbWO4 EMCAL in Geant4

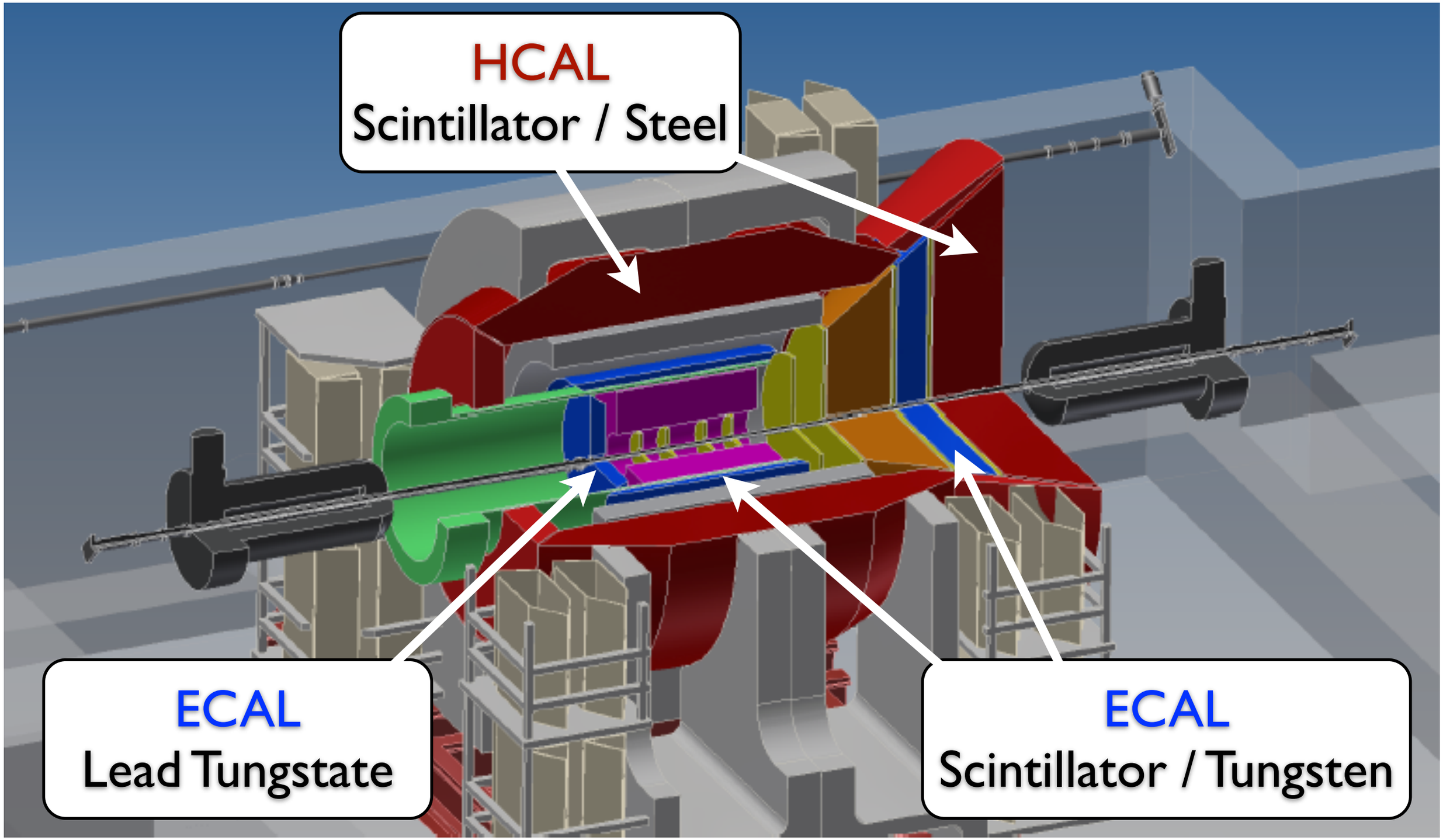


e/μ/π
10 GeV





ePHENIX Calorimeters



Summary

- Energy measurements with calorimeters play an important role in various fields.

- Basic principle: Generated signal ~ deposited Energy.

- Calorimetry for hadrons more challenging than for electrons / photons because of
  - ✦ large fluctuations
  - ✦ ‘invisible’ energy depositions

Recommended Resources

- K. Nakamura et al., "Review of Particle Physics," J. Phys., vol. G37, p. 075021, 2010 (http://pdg.lbl.gov/).

- N. Feege, "Low-energetic Hadron Interactions in a Highly Granular Calorimeter," Ph.D. dissertation, University of Hamburg, 2011, DESY-THESIS-2011-048 (http://www-library.desy.de/preparch/desy/thesis/desy-thesis-11-048.pdf).

- R. Wigmans, "Calorimetry," Scientifica Acta 2, No. 1, 18 – 55, 2008.

- R. Wigmans, *Calorimetry*, 1st ed. Oxford University Press, 2000.